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ADAPTIVE TRANSMIT POWER CONTROL SYSTEM

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BACKGROUND

Field of the Disclosure

[0001] The present disclosure relates to power control systems, and more particularly to adaptive power control systems that do not require factory calibration of loop control parameters.

Description of the Related Art

[0002] In current power control systems, transmit (Tx) power ramp up and down curves are controlled by altering the control or bias voltage applied to a power amplifier or a voltage controlled amplifier (VCA) modulator integrated circuit. For example, the controls to meet power control specification requirements, such as power versus time and transient adjacent channel power masks for GSM-FracN, WCDMA, and Cartesian IQ multiple access modes, are typically performed by a closed loop power control system.

[0003] Current closed loop power control systems require extensive factory calibration because the control voltage applied versus the transmit power output characteristics of the power amplifier or VCA stage as well as that of the power detection feedback path vary depending on the frequency band of operation, the input power level to the power amplifier, and variations in temperature and battery voltage.

[0004] Because of tri-band requirements (GSM, DCS or the PCS bands) of some systems, the slope of the control voltage versus the transmit power out characteristics changes with each frequency band of operation. In addition, the power amplifier transmit power versus the detected power characteristics of the power detector also vary with the different bands of operation.

[0005] The slope of the control voltage versus transmit power output curve varies with respect to input power levels (dBm) at the power amplifier. Prediction of variations of the power input to the power amplifier and programming of corresponding system parameters is difficult. The slope of control voltage versus the transmit power output curve also changes with temperature and battery voltage variations.

[0006] In order to meet loop stability and performance requirements including power versus time mask and switching transient specifications, different AOC system parameters, for example, loop bandwidths and the analog feedback gains , have to be programmed for each frequency band of operation, for different power inputs, and for different temperature and battery voltage variations. Typically, pre-calibrated fixed settings for the loop bandwidths during transmit ramp up and ramp down are used. The factory calibration of the power control loop bandwidths is a complex task which has to be performed as a function of the frequency band of operation, input power levels to the power amplifier, initial and final target power level, temperature, and supply voltage. Factory calibration is time intensive and costly.

[0007] A transmit power control system which does not need extensive factory calibration of power control loop bandwidths over the power transition ranges, frequency bands of operation, temperature and supply voltage is desired.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The present disclosure may be better understood, and its numerous features and advantages made apparent to those skilled in the art by referencing the accompanying drawings.

[0009] FIG. 1 illustrates a block diagram of a power control system according to an embodiment of the present disclosure.

[0010] FIG. 2 illustrates a detailed block diagram of a portion of a power control system according to an embodiment of the present disclosure.

[0011] FIG. 3 illustrates a transmit power vs. time plot for a closed-loop WCDMA system according to an embodiment of the present disclosure

[0012] FIG. 4 illustrates a power vs. time mask curve and the switching transients during a transmit power ramp up and ramp down of a GSM burst according to an embodiment of the present disclosure.

[0013] The use of the same reference symbols in different drawings indicates similar or identical items.

DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

[0014] An adaptive transmit power control system which does not require extensive factory calibration of power control loop bandwidths over the power transition ranges, frequency bands of operation, temperature, and supply voltage is disclosed. The system automatically compensates for any gain or slope variations in the power control feedforward path as well as in the power detect feedback path to maintain system stability and meet desired performance specifications. The system includes an adaptive digital signal processing system architecture to accomplish this.

[0015] FIG. 1 illustrates a block diagram of a power control system according to an embodiment of the present disclosure. Power control system 100 includes well known components such as a radio frequency (RF) transmitter 102, a coupler 104, an RF power detector 106, a programmable gain circuit 108, a detect filter 110, an analog to digital converter (ADC) 112, digital activity detection unit 114, reference ramp look up table 116 whose output is multiplied by the target final power level, loop filter 118, power control digital to analog converter (DAC) 120, reconstruction filter 122, analog gain control stage 124, and power amplifier 126. These devices and their operations are well known in the art. Any deviations from conventional operation are only as noted herein. For example, according to an embodiment of the present disclosure, loop filter 118 receives fixed loop bandwidths.

[0016] Power control system 100 also includes an error squaring block 204, an adaptive filter coefficients calculation unit 128 and an N-tap adaptive filter 130. The number of the taps of adaptive filter 130 can be programmable. In operation, the coefficients of adaptive filter 130 are adjusted based on the difference between a reference ramp D_k and feedback signal A_k. The N tap adaptive DSP system is configured to track any gain/slope variations in the analog feedforward and feedback

paths of the power control system. It will be appreciated that the error squaring block 204 may be considered part of the filter coefficients calculation unit 128.

[0017] FIG. 2 illustrates a more detailed block diagram of a portion of a power control system according to an embodiment of the present disclosure. D_k is the desired input signal, and A_k is the signal that has to ideally track D_k irrespective of any gain/slope variations in the analog feedforward and feedback paths. The difference between them $E_k = D_k - A_k$ is used to adjust the taps of adaptive filter 130 by employing an adaptive technique, such as a least mean square (LMS) adaptive algorithm. The output of the adaptive filter S_k converges to zero following closed loop adaptation, thus forcing the loop to settle to a desired steady state target power level.

[0018] The algorithm is described for an N=2 tap example, though it will be appreciated that other numbers of taps can be used. An initial weight vector $W_0 = [w_{10} \quad w_{20}]^T$ is assumed. The difference $E_k = D_k - A_k$ is calculated by summation unit 202 on a sample-by-sample basis. The error signal E_k is then squared by square unit 204 and used to adapt the filter taps of adaptive filter 130 as illustrated in FIG. 2 and as described by the following equations. For the iteration k, the output of adaptive filter 130, $S_k = E_k w_{1k} + E_{k-1} w_{2k}$, is calculated. The weights are then updated according to the LMS algorithm, $W_{k+1} = W_k + 2\mu E_k^{\ 2}$ by summation unit 206. The initial weight vectors and the initial input vectors E_k's are assumed to be zero. The convergence factor μ determines the stability and the speed of convergence. The output of adaptive filter 130 feeds loop filter 118. According to an embodiment of the present disclosure, loop bandwidths are set close to an optimal setting and the adaptive algorithm adjusts for any gain/slope variations with the control loop to meet power control specifications. The Equations 1 to 5 summarize a specific embodiment of the adaptation process.

[0019] (Equation 1) $E_k = D_k - A_k$

[0020] (Equation 2) $W_k = [w_{1k} \quad w_{2k}]$

[0021] (Equation 3) $S_k = E_k w_{1k} + E_{k-1} w_{2k}$

[0022] (Equation 4) $= \lfloor E_k E_{k-1} \rfloor \begin{bmatrix} w_{1k} \\ w_{2k} \end{bmatrix}$

[0023] (Equation 5) $W_{k+1} = W_k + 2\mu E_k^{\,2}$

[0024] Both plots in Fig. 3 show a power up change from 15 dBm to 24dBm at the antenna. Both plots in this figure show the Power versus Time response for the on-channel signal as well as that at the adjacent channel (5 MHz offset), and alternate channel (10 MHz offset). The plot on the left shows these responses without using the proposed adaptive signal processing scheme whereas the one on the right shows these responses using the proposed adaptive signal processing scheme. In the plot on the left, the power control system fails to meet the 50 us required settling time for the on-channel power by employing a fixed loop bandwidth programmed in the loop filter without using the proposed adaptive signal processing technique. Alternately, in the plot on the right, by employing the proposed adaptive signal processing scheme we are able to meet the 50 us settling time for the on-channel signal with a fixed loop bandwidth. FIG. 4 illustrates the power versus time mask during a transmit power ramp up and ramp down of a GSM-FracN burst according to an embodiment of the present disclosure. The power control system compensates for the inappropriate settings of the loop bandwidths (-22 dB instead of -11 dB). For the same power level of operation (26 dBm), the loop bandwidths do not need to be modified to a different value in order to meet the Power vs. Time Mask and the switching transient specifications.

[0025] Simulations indicate that the adaptive algorithm according to an embodiment of the present disclosure can compensate for up to +/-11 dB variations in the closed loop system gain using a fixed convergence factor to meet the desired power versus time and transient power specifications. The algorithm converges nominally without causing any additional switching transients.

[0026] By employing the disclosed system, the need for factory calibration of the closed loop parameters for each band and for each input power levels of the PA can be eliminated, thus saving time and money. In addition, power amplifier droop compensation circuits can be eliminated because the filter taps are adjusted sample by sample and track the reference ramp and thus compensate for any power amplifier droops in the analog RF transmit path. Further, the since the closed loop system is more tolerant to gain variations in the feedforward and feedback paths, it provides a more stable and robust control system.

[0027] Although the embodiments disclosed in the figures describe the use of a power amplifier, those skilled in the art will recognize that the disclosed closed loop DSP algorithm can control an arbitrary analog gain control stage. The arbitrary analog gain control stage can be a baseband amplifier. Alternatively, the arbitrary analog gain control stage can be an RF amplifier where the RF amplifier is a voltage controlled amplifier or a power amplifier.

[0028] The above-disclosed subject matter is to be considered illustrative, and not restrictive, and the appended claims are intended to cover all such modifications, enhancements, and other embodiments that fall within the intention and scope of the present invention. Thus, to the maximum extent allowed by law, the scope of the present invention is to be determined by the broadest permissible interpretation of the following claims and their equivalents, and shall not be restricted or limited by the foregoing detailed description. For example, another adaptive algorithm like the recursive least squares (RLS) technique could be adopted.